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ENVIRONMENTAL TOBACCO SMOKE: CONCENTRATION AND EXPOSURE

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Environmental tobacco smoke (ETS) is often cited as a key factor in indoor air quality (IAQ) and public health. However, there are few studies which attempt to actually calculate the impact ETS has on IAQ or the doses of ETS one may receive from possible exposure in a variety of different settings. This paper reviews the data on indoor air published since 1980 and estimates the portion of various constituents which are produced by ETS. It can be observed that, in most instances, ETS has only a minor impact on IAQ. Retained doses of ETS particles are calculated for various exposure scenarios using respirable particle concentrations associated with ETS, time activity patterns, respiration rates and retention rates. Total doses range from 3–40 mg/y. This dose level does not seem to support the summary relative risk of 1.35 that has been claimed from meta-analyses of epidemiologic studies of spousal smoke exposure and lung cancer.

INTRODUCTION

Interest in indoor air quality (IAQ) is steadily increasing. The factors which affect IAQ and the health effects reportedly associated with it are the subject of intense debate. One of the IAQ issues which generates the most interest and emotion is environmental tobacco smoke (ETS) exposure and its reported health effects. ETS exposure has been claimed to be associated with health effects as diverse as childhood respiratory disease, lung cancer, and cardiovascular disease (Repace and Lowrey 1985; U.S. Surgeon General 1986; National Research Council 1986; Wells 1988; Glantz and Parmley 1991; USEPA 1990).

ETS is a complex mixture of many substances, the concentrations of which will vary with time, room ventilation, and proximity to the source. Since not all of its components are removed from the environment at the same rate, the concentrations of ETS components also vary in relation to each other over time. Because of this, it is difficult to accurately determine exposure to ETS and, further, whether the health claims are realistic in terms of this exposure.

Sterling et al. (1982) performed a comprehensive review of components of ETS measured in different environments and under different smoking conditions. Since that review was completed, there have been many changes in both indoor environments and analytical methodology. Because of this, a new review of the literature pertaining to indoor air quality and environmental tobacco smoke is appropriate.

This study assesses the literature on indoor air quality and ETS published since 1980. Using the data collected, it also attempts to determine what levels

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of substances measured indoors may result from the presence of ETS and calculates some of the doses which may be expected from ETS.

INDOOR AIR AND ETS REVIEW

Methods

The literature search was restricted to work which took place in the U.S. and Canada and was published after 1980. There is important IAQ data being generated in European and other countries. However, potential differences in building age, ventilation types, room sizes and other factors may prevent data from other countries from being comparable to the U.S./Canadian data. This study limited the literature to the countries where the data were believed to be more homogeneous and essentially reviewed the literature published since the Sterling et al. (1982) review.

The following indoor air components were chosen for evaluation: respirable particulates (RSP); carbon monoxide; nicotine; nitrogen dioxide; formaldehyde; benzene; polycyclic aromatic hydrocarbons (PAH); and nitrosamines.

When it was obvious that structures and sampling protocol for data acquired in countries outside North America were similar, it was included with the USA/Canada data. In instances where relatively little information was available or the data from all countries were similar, information from other countries also was used.

The information was recorded in the following categories:

1. Homes—includes single family dwellings and apartments.
2. Offices, workplaces, and public facilities—includes offices, work sites, schools, universities, hospitals, retail stores, museums, libraries, clinics, grocery stores, laundromats, and public transportation stations.
3. Restaurants
4. Bars/taverns—includes betting shops, billiard parlors, bars, and taverns.
5. Public transportation—trains, buses, subway, and autos.

The data were selected from the literature using the following criteria:

If no mean was given, generally, the data were not reported in this document unless there were individual values given to make it possible to calculate a mean. If there were 10 or more samples and a median was given, the data were reported. Both arithmetic and geometric means are reported. If an arithmetic mean was given, it was used in any subsequent calculations.

If only a [illegible] the data were not used because the sample at one point in time is not as representative [illegible] several samples at different [illegible] longer duration.

For respirable particulates, if the data were reported as total particulate matter (TPM), the data were not used. If the sample was PM 5.0 or less, the data were reported.

The data were recorded with a preference for gravimetric data on RSPs. When gravimetric, light scattering, and piezobalance data were all present, the gravimetric data were used. If data from only one of these three methods were present, these data were used.

This paper focuses upon the scientific literature pertaining to the quantification of indoor air quality. Hence, the papers reviewed are those that have measured levels of substances in indoor air. Odor may play a part in the acceptability of indoor air to occupants or visitors to any particular environment, but the evaluation of odor in offices is as yet somewhat subjective and poorly quantified. ETS clearly may influence odor perception in some situations, and the existing scientific literature on this matter has been reviewed. Because of both the scarcity of data on this issue and the subjectivity of the data that do exist, odor has not been considered as a quantified element in the data tabulated in this report.

Results

The results of the literature review on indoor air components are in Tables 1-8. Each table is a summary of one of the components reviewed. Units of measurement in the tables are reported the same as authors presented them in their studies. Conversion factors for ppm (parts per million) and ppb (parts per billion) to $\mu g/m^3$ are given where appropriate. Tables 9, 10, and 11 summarize the data for RSPs, CO, and nicotine. Nitrogen dioxide, formaldehyde, benzene, PAH, and nitrosamine data are summarized in the discussions.

DOSIMETRIC CALCULATIONS

Methods

The particle fraction of ETS is the portion on which the majority of the health claims concentrate. An estimate of the dose of ETS particles that persons

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Table 1. Respirable particles (RSPs) measured under realistic conditions.

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations
Carson & Erikson (1988)	Canada	Offices (31)	≥ 2 people w/min. 1 smoker	Not Given	PASS Unit PM3.5 9 hr samples (8-5)	UVPM ($\mu g/m^3$): A. Mean 44; G. Mean 24; Range 6 - 426
Conner, et al. (1986)	USA	Homes (10) Restaurants (10)	Not Given	Not Given	Gravimetric & UVPM Personal Pump, 120-180 min. samples.	RSP ($\mu g/m^3$) / UVPM ($\mu g/m^3$): Homes, Range 17 - 86 / 1 - 8; Homes, A. Mean 58 / 4.2; Rest., Range 18 - 306 / 15 - 223; Rest., A. Mean 169 / 106
Conner, et al. (1989)	USA	Offices (10) Planes (5)	Not Given	Not Given	Gravimetric PM3.5 PASS Unit, 1-5 hr samples	RSP ($\mu g/m^3$) / UVPM ($\mu g/m^3$): Offices, Range 167 - 1088 / nd - 147; Offices, A. Mean 448 / 65; Planes, Range (Smoking Section) 33 - 119 / 20 - 106; Planes, A. Mean (Smoking Section) 72.6 / 66.6; Planes, Range (Non Smoking Sect.) 3 - 98 / 12 - 30; Planes, A. Mean (Non Smoking Sect.) 22 / 18.6
Coultas, et al. (1990a)	USA	Workplace(15)	Not Given	Not Given	Gravimetric Personal Monitors 6.5 hours, PM2.5	Males: Hospital 2, 66.15; Offices 2, 56.7; Barber Shop 2, 80.25; Restaurant 1, 145.8; Retail Store 1, 85.2. Females: Hospital 3, 35.33; Offices 3, 70.37; Public Trans. 1, 4.0 (Samples / Avg. RSP ($\mu g/m^3$))
Coultas,et al. (1990b)	USA	Homes (10)	Not Given	Not Given	Gravimetric PM2.5 10 samples/home	RSP Means - 32.4 - 76.9 $\mu g/m^3$
Cousins & Collett (1989)	Canada	Schools (3) Portables (6)	Not Given	Not Given	Light Scattering PM5.0	RSP ($\mu g/m^3$): Old School / Ren. School / New School / Port. Class. — Indoor 16 (11-22) / 13 (10-20) / 14 (10-17) / 17 (15-20); Outdoor 23 / 15 / 18 / 18
Crouse & Carson (1989)	USA	Offices(32) & Restaurants (36)	Not Given	Not Given	Gravimetric PM3.5	Geo. Mean / Range ($\mu g/m^3$): Offices RSP 61 / 11 - 279; UVPM 47 / 11 - 84; Restaurants RSP 111 / 16 - 366; UVPM 31 / 10 - 194
Crouse, et al. (1988)	USA	Restaurants (37)	Not Given	Not Given	Gravimetric PM3.5 1 Hour Sample	Geo. Mean / Arith. Mean / Range ($\mu g/m^3$): RSP 62 ± 2.2 / 80.8 / 16 - 221; UVPM 26.1 ± 1.9 / 34.1 / 15 - 168

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Table 1. Continued.

Daisey, et al. (1989)	USA	Homes (7)	Not Given	0.13-0.89 ACH	Gravimetric w/ Cyclone, 48 hr samples	House # / Indoor / Outdoor (+ = Woodburning): 102 + 37.5 / 24; - 30.4 / 13.8; 106 + 33.3 / 30.9; - 57.7 / 7.2; 108 + 36.6 / 38.4; - 27.6 / 27; 203 + 19.7 / 32.4; - 20.3 / 4.5; 204 + 35.4 / 10.5; - 27.3 / 9.6; 208 + 47.6 / 19.9; - 29.9 / -; 300 + 60.1 / -; - 35.6 / -. Mean - Woodsmoke 32.7
Eudy, et al. (1987)	USA	Restaurant	Not Given	Not Given	Gravimetric PM3.5 4 hr samples, 12 samples/48 hr run	RSP, 5 - 48 hour sample runs. Range 0 - 105 $\mu g/m^3$. A. Mean 29.3 $\mu g/m^3$
First, (1983)	USA	Public Places	Various	Not Given	Piezobalance	Site / Avg. Conc. ($\mu g/m^3$): Chamber1 300 - 1 cig. smoked; Chamber2 290 - 1 cig. smoked; School cafeteria1 20 - no smokers; School cafeteria2 40 - 2-3 smokers; Tavern1 400 - 1-5 smokers; Tavern2 660 - 2-3 smokers; Tavern3 570 - mostly 1 smoker; Bus Terminal 110 - 50-100 people, 1-5 smokers; Bus Terminal (outside) 70; Fast Food Restaurant 150 - 1-3 smokers during sampling; Sm. Sitdown Rest.1 250 - 15 diners, 4 smokers; Sm. Sitdown Rest.2 260 - 23 diners, 1 smoker
Georghiou, et al. (1989)	Canada	Ice Arena	Varied	Not Given	PM10 Indoor Sampling Impactor, 2.5 hr samples 10 games	Smoking Allowed: Range 17 - 680 $\mu g/m^3$; A. Mean 440.75 $\mu g/m^3$ (n=4). Smoking Restricted: Range 187 - 426 $\mu g/m^3$; A. Mean 302.57 $\mu g/m^3$ (n=7)
Grimsrud, et al. (1990)	USA	Office Buildings (40)	Not Given	Not Given	Gravimetric PM3.0 3-20 sampling sites/ building	Concentration ($\mu g/m^3$): Arithmetic Mean 30.0; Geometric Mean 24.0; Range 5 - 86
Hedge, et al. (1990)	USA	Office Buildings (2)	Not Given	Not Given	Piezobalance, Gravimetric PM2.5, UVPM	Area / Method / Date ($\mu g/m^3$) AM / PM: Building (NS) Piezobalance 20 / 10; Office (Restricted S) Piezobalance 40 / 40; Smoking Area w/filter Piezobalance 110 / 140; Building (NS) Gravimetric N/A / N/A; Office (Restricted S) Gravimetric 200 / 300; Smoking Area w/filter Gravimetric 350 / 400; Building (NS) UVPM 0 / 0; Office (Restricted S) UVPM 9.0 / 7.0; Smoking Area w/filter UVPM 120 / 185

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Table 1. Continued.

Hollowell and Miksch 1981	USA	Office (1)	Not Given	Not Given	12 Hours	"Particles" - - - 31 $\mu g/m^3$ Avg.
Hosein, et al. (1985)	Canada	Homes	Not Given	Not Given	Gravimetric (RSP) 24 hr. samples	RSP ($\mu g/m^3$, Geometric Mean) AC / No AC Smoke (n=11) 80.5 (n=25) 70.11 No Smoke (n=4) 34.3 (n=11) 32.5 Carpet / No Carpet Smoke (n=28) 76.6 (n=8) 70.2 No Smoke (n=9) 38.7 (n=7) 53.7 Hot Water / Forced Air Smoke 84.8 57.1 No Smoke 66.7 37.7
IT Corp. (1987)	USA	Restaurants (36) Offices (38)	Varied	Not Given	Gravimetric PM3.5 PASS Unit 1 Hour Samples	RSP ($\mu g/m^3$) / UVPM ($\mu g/m^3$) Offices Range nd-375 / nd-108 Offices A. Mean 114 / 28.3 Restaurants Range nd-417 / nd-127 Restaurants A. Mean 120 / 33.2
Leaderer, et al. (1990)	USA	Homes (394)	Not Given	Not Given	Gravimetric PM2.5	Source / n / Suffolk / n / Onondaga ($\mu g/m^3$) None 30 17.3 45 14.1 W 15 18.1 16 19.1 K 7 22 4 21.2 S 61 49.3 80 36.5 KW 4 19.7 SW 29 38 31 33.9 SK 23 61.4 4 35.3 SKW 6 30.3 4 28.5 Outdoor 19 16.9 36 15.8 W = Woodstove K = Kerosene S = Smokers
Lofroth, et al. (1989)	USA	Tavern (1)	5 - 25 180 m^3 Smoking Allowed	Not Given	Gravimetric TSP & Piezobalance	First Study (3 hr) Indoor / Outdoor; Second Study (4 hr) Indoor / Outdoor TSP 470 nd 390 nd Piezobalance 420 < 50 320 40
McCarthy, et al. (1987)	USA	Homes (68S, 13NS)	Not Given	Not Given	Gravimetric (RSP) Personal & Area Samples (24 hr)	Mean / Median / Range ($\mu g/m^3$) Personal (NS) 29.4 27.2 21.6-39.8 Personal (S) 56.2 52.6 18.0-116.3 Home (NS) 30.9 25.6 16.6-77.1 Home (S) 54.6 55.6 --- Personal Samples on Children (8-11 yr old)
Miesner, et al. (1988)	USA	Public Places, Offices (19)	Varied	Varied	Gravimetric PM2.5 3-16 Hours	Mean RSP ($\mu g/m^3$) NS Areas (n=33) 14 Smoking Areas (N=7) 36.5 Trans. Facility (n=4) 64 (Subways or Bus)

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Table 1. Continued.

Miesner, et al. (1989)	USA	Public Bldgs (21)	Not Given	Not Given	Gravimetric PM2.5

Samples		Range ($\mu g/m^3$)	A. Mean ($\mu g/m^3$)
4	Library (NS)	5.8 - 12.8	9.08
4	High School (NS)	12.5 - 109.4	41.9
2	Museum 1 (NS)	6.5 - 11.0	8.75
2	Museum 2 (NS)	nd - 12.9	6.45
4	Hospital (NS)	14.5 - 23.3	17.35
2	Hospital (S)	20.1 - 52.5	36.3
4	Clinic (NS)	nd - 17.3	9.3
1	Clinic (S)	119.1	119.1
2	Groc. Store (NS)	11.9 - 14.0	12.95
1	Laundromat1 (NS)	17.2	17.2
1	Laundromat2 (NS)	24.3	24.3
2	Bar/Rest.1 (S)	36.3 - 107.3	71.8
2	Bar/Rest.2 (S)	133.1 - 140.9	137
3	Bar 3 (S)	30 - 78.3	59
2	Subway St.1 (NS)	91.7 - 157.3	124.5
2	Subway St.2 (NS)	55.1 - 66.5	60.8
1	Bus Station (NS)	43.3	43.3
2	Office Bdg1 (S)	16.2 - 18.6	17.4
1	Office Bdg2 (NS)	15.8	15.8
2	Office Bdg3 (NS)	17.3 - 18.2	17.75
3	Office Bdg4 (S)	26 - 80	44.73
2	Office Bdg4 (NS)	15 - 15.2	15.1
1	Office Bdg5 (S)	520.8	520.8
4	Office Bdg5 (NS)	11.1 - 20	14.83
2	University (S)	114 - 196	155
2	University (NS)	5.6 - 44.3	24.95

Millar (1988)	Canada	Office Buildings (2)	Not Given	Not Given	Piezobalance Pre and 1yr Post smoking ban

Floor	Building A	Floor	Building B
7th Pre	30 $\mu g/m^3$	3rd Pre	35 $\mu g/m^3$
9th Pre	28	15th Pre	47
7th Post	22	3rd Post	18
9th Post	22	15th Post	25

Ogden and Maiolo (1989)	USA	Homes (2) Auto (1) Dep't Store (1) Billiard Parlor (1)	Not Given	Not Given	Gravimetric PM3.5 Personal Pumps 2-8 hr samples

	Sample Duration	No. of Cigs.	Conc. ($\mu g/m^3$) RSP	Conc. ($\mu g/m^3$) Solanesol
Billiard Parlor	2 hr	34[a]	355	12.8
Home	4 hr	6[b]	187	6.4
Home	4 hr	6[b]	212	6.6
Dep't Store	4 hr	0	55	ND
Automobile	8 hr	0	18	ND

[a] Actual Count, 30 cigs., 4 cigars.
[b] Kitchen only.

Oldaker, et al. (1990)	USA & Canada	Restaurants & Offices, 4 cities	Min. 2/off. w/ 1 smoker	Not Given	Gravimetric PM3.5 PASS Unit, Sampled during lunch & dinner hours.

	Offices ($\mu g/m^3$)	Restaurants ($\mu g/m^3$)
RSP Range	(n=131) 0 - 1,088	(n=83) 0 - 685
RSP Mean	126	126
UVPM Range	(n=125) 0 - 287	(n=82) 0 - 184
UVPM Mean	27	36

Oldaker, et al. (1988)	USA	Offices & Restaurants	Not Given	Not Given	Gravimetric PM3.5

		RSP ($\mu g/m^3$)	UVPM ($\mu g/m^3$)
Offices (n=45)	GM	95	(n=43) 24
	AM	107	33
	Range	7-258	2-170
Restaurant (n=47)	GM	175	(n=49) 47
	AM	199	61
	Range	57-658	7-163

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Table 1. Continued.

Ozkaynak, et al. (1990)	USA	Homes (9)	18 participants	0.2 -0.8 ACH	Gravimetric PM2.5 Stationary & Personal Samples	

	N	Average	St. Deviation	Range - $\mu g/m^3$
Indoors	230	37.31	24.27	6.97-168.82
Personal	52	75.09	46.82	19.90-240.56
Outdoor	101	42.72	23.97	8.98-116.87

Proctor (1989)	UK	Offices (10) Train Comp.(20)	app. 75%	Mechanical	Gravimetric PM3.5 PASS Unit, 1 Hr Samples	

($\mu g/m^3$)	RSP Range	RSP Mean	UVPM Range	UVPM Mean
Offices(S)	33-260	103	.5-75	23
Office(NS)	29-240	90	1-17	8
Trains (S)	70.8-325	216	13-110	59.8
Trains (NS)	63.3-450	186	9-105	33

Proctor, et al. (1989b)	UK	Office (1)	26 m^2/ person	Not Given	Gravimetric PM3.5 10 sites sampled 5 times each	

	RSP ($\mu g/m^3$)	UVPM ($\mu g/m^3$)
S Mean -	103	23
Median -	91	24
NS Mean -	90	8
Median -	71	8.8

Quackenboss, et al. (1989a)	USA	Homes (98)	Not Given	Not Given	Gravimetric PM10 & PM2.5	

Smoking	Evap. Cool.	n	PM2.5 ($\mu g/m^3$)	n	PM10 ($\mu g/m^3$)
	Yes	20	8.8	20	21.0
No	No	25	20.3	23	38.4
	Total	45	15.2	43	30.3
	Yes	10	19.3	10	33.9
1-20/day	No	16	32.3	17	53.4
	Total	26	27.3	27	46.2
	Yes	8	36.2	9	47.4
>20/day	No	9	82.7	9	102.5
	Total	17	60.8	18	75.0

Quackenboss, et al. (1991)	USA	Homes (200)	Not Given	Not Given	Gravimetric PM2.5 2 weeks of sampling	

	Smokers at Home		No Smokers at Home	
Season[a]	N	Median $\mu g/m^3$	N	Median $\mu g/m^3$
Summer	49	20.5	50	8.9
Spring/Fall	39	20.1	37	10.6
Winter	24	35.7	26	13.4

[a]Seasons: Summer = May - September
Spring/Fall = March, April, October, November
Winter = December - February

Santanam, et al. (1990)	USA	Homes (280) 70S, 70NS each city	Not Given	Not Given	Gravimetric PM2.5 1 week samples	

Steubenville (RSP $\mu g/m^3$)

Winter		Summer	
S Homes	NS Homes	S Homes	NS Homes
43.57	19.54	49.85	29.5

Portage (RSP $\mu g/m^3$)

Winter		Summer	
S Homes	NS Homes	S Homes	NS Homes
34.6	14.8	24.9	13.9

Sheldon, et al. (1988a)	USA	Home for Elderly (2)	Not Given	Not Given	Dichotomous Impactors < 2.5μm	

RSP <2.5μm ($\mu g/m^3$) Mean of 3 - 24 Hour Samples

	Home #2	Home #1
Apartment (S)	89	39
Commons Area	16 (smoking observed)	30 (smoking lounge)
Apartment (NS)	9	9
Outdoors	4 (1 24 hr sample)	10

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Table 1. Continued.

Spengler, et al. (1985)	USA	Homes Offices Workplace (Non-office)	Not Given	Not Given	Gravimetric PM2.5	Building Type / Smoking ($\mu g/m^3$) / Non-smoking ($\mu g/m^3$) Homes N = 80 / 186 A. Mean 74 / 28 Offices N = 31 / 80 A. Mean 67 / 24 Workplace (Non-office) N = 9 / 6 A. Mean 50 / 23
Spengler, et al. (1987)	USA (6 cities)	Homes App. 300	Not Given	Not Given	Particle Sampler PM2.5 Week Long Samples	Range of Means - Homes Non Smoking 15 - 35 $\mu g/m^3$ Smoking 35 - 75 $\mu g/m^3$ Homes w/smokers 30$\mu g/m^3$ (Mean) > Homes w/o smokers
Sterling & Mueller (1988)	Canada	Office Building (2)	Not Given	Mechanical/ Re-circulated Air Pass. Vent/No Re-circulation	Light Scattering, Digital Dust Counter < 5 μm	# Samples / RSP ($\mu g/m^3$) Cafeteria (S) 6 / 102.5 Cafeteria (NS) 6 / 64.5 Offices (NS) 8 / 6.0 Offices (NS) 2 / 7.0
Sterling, et al. (1988)	USA & Canada	Offices	Not Given	Not Given	?	"Particles" ND - 2.7 mg/m^3 (0.04 median) 85 samples
Thomas, et al. (1989)	USA	Industrial Cafeteria	30 ± 9 560 m^3	8.8 ACH 2900 cfm OA, 2500 cfm RA	Gravimetric PM3.5 2 hrs/day for 14 Days (Lunchtime)	Lunchtime ($\mu g/m^3$) / Background ($\mu g/m^3$) RSP 60 ± 50 / 10 ± 10 UVPM 54 ± 33 / < 1 (Avg. Smoking Rate During Sampling was 26 ± 6 cig/hr)
Turner, et al. (1991)	USA	Offices (585)	126.5 ft^2/ person	Not Given	Piezobalance	N / RSP ($\mu g/m^3$) means Smokers 331 / 46.37 Non smokers 254 / 20.11 Total 585 / 34.97
Weschler and Shields (1989)	USA	Phone Switching Office (1)	Not Given	Not Given	Gravimetric PM2.5 1 week samples	Week / Indoors ($\mu g/m^3$) / Outdoors ($\mu g/m^3$) Apr. 7-14 0.85 7.41 Apr. 14-21 1.22 10.33 Apr. 21-28 3.05 17.85 Apr. 28 - May 5 0.67 7.80 May 5-12 3.50 16.62 May 12-19 4.12 17.59 May 19-26 2.41 12.40 May 26 - June 2 3.12 20.24
Yocom, (1982)	USA	School, Homes (1) (2)	Not Given	(See Results)	Resp. Part. Matter PM2.5	RPM @ Elementary School ($\mu g/m^3$) Vent. (m^3/h/person) / Indoors / Outdoors 10.8 / 19.0 / 26.3 9.1 / 11.7 / 15.3 2.5 / 15.5 / 26.3 RPM in Home Pre & Post Energy Efficient Retrofit Pre: Indoor / Outdoor; Post: Indoor / Outdoor Home 1, S 31 / 10 / 36 / 11 Home 1, NS 9 / 14 / 8 / 13 Home 2, NS 12 / 9 / 10 / 10

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Table 2. Carbon monoxide (ppm) measured under realistic conditions (Conversion factor: 1ppm = 1.15 mg/m³).

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations/Comments
Carson & Ericson (1988)	Canada	Offices (31)	≥2 people w/min. 1 smoker	Not Given	Electrochemical Detector in PASS Unit, 1 sample/ minute	A. Mean: Indoor 1.9, Outdoor 1.9 G. Mean: 1.3, 1.2 Min.: <.1, <.1 Max.: 8.7, 5.8 No. of Offices: 28, 21
Cousins & Collett (1989)	Canada	Schools (3)	Not Given	Not Given	Electrochemical Analyzer	CO (ppm): Old School / Renovated School / New School / Portables A. Mean: 1.3 / 1.1 / 0.9 / 0.9 Range: 1.0-1.8 / 0.7-1.5 / 0.7-1.1 / 0.8-1.0 Outdoor: 2.1 / 11.5 / 1.1 / 1.1
Crouse, et al. (1989)	USA	Offices (30) Restaurants (30)	Not Given	Not Given	PASS Unit, Electrochemical Detector	N / Range (ppm) / A. Mean (ppm) Offices-Outdoors: 29 / 0.2-7.2 / 2.8 Offices-Indoors: 29 / 0.6-7.1 / 2.5 Restaurants-Outdoors: 31 / 0.2-9.2 / 3.4 Restaurants-Indoors: 31 / 0.4-12 / 5.0
Crouse, et al. (1988)	USA	Restaurants (36)	Not Given	Not Given	PASS Unit	CO (ppm): N = 36; Range = 0.9 - 6.3; G. Mean = 2.4; A. Mean = 2.6; St. Deviation = 1.5
Eudy, et al. (1987)	USA	Restaurant	Not Given	Not Given	Electrochemical Analyzer, Sample every 10 mins. during 48 hr runs	CO (5) 48 Hour Sampling Runs Range: 0 - 16 ppm A. Mean: 4 ppm
First (1983)	USA	Public Places	Various	Not Given	Ecolyzer	Site / Avg. Conc. (ppm) Chamber1: 2.0 - 1 cig. smoked Chamber2: 1.5 - 1 cig. smoked School cafeteria1: 1.0 - no smokers School cafeteria2: 0.5 - 2-3 smokers Tavern1: 8.0 - 1-5 smokers Tavern2: 8.0 - 2-3 smokers Tavern3: 7.0 - mostly 1 smoker Bus Terminal: 3.5 - 50-100 people, 1-5 smokers Bus Terminal (outside): 2.0-2.5 Fast Food Restaurant: 5.0 - 1-3 smokers during sampling Sm. Sitdown Rest.1: 6.0 - 15 diners, 4 smokers Sm. Sitdown Rest.2: 6.5 - 23 diners, 1 smoker
Flachsbart, et al. (1987)	USA	Car (8) Bus (4) Train (3)	Not Given	Not Given	Electrochemical Detector No Smoking	N[a] / Range of Means (ppm) / A. Mean of means (ppm) Automobile: 213 / 8.8 - 22.3 / 11.6 Bus: 35 / 3.7 - 10.2 / 6.0 Train: 8 / 2.0 - 5.2 / 2.88 [a]N=number of trips
Hedge, et al. (1990)	USA	Office Building (2)	Not Given	Not Given	Direct Reading Interscan 4000 Hourly Samples	A. Mean (ppm): AM / PM Smoking Prohibited: 0.0 / 0.0 Smoking Restricted (Office): 2.5 / 1.7 Smoking Restricted (Office with des. smoking area w/LACS[a]): 2.8 / 2.6 [a]Local Air Cleaning System

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Table 2. Continued.

IT Corp. (1987)	USA	Offices (38) Restaurants (36)	Varied	Not Given	Electrochemical Detector, sampled each min. for 60 min.	Offices: Range (ppm) 0.5 - 6; A. Mean (ppm) 1.9. Restaurants: 0.4 - 9; 3.1
Lofroth, et al. (1989)	USA	Tavern	5-25 people 180 m^3	Not Given	Electrochemical Detector	First Study (3hr): Indoor 4.4 mg/m^3; Outdoor < 1 mg/m^3. Second Study (4hr): Indoor 4.8 mg/m^3; Outdoor 1-2 mg/m^3
Mumford, et al. (1990)	USA	Mobile Homes	Not Given	0.5 ACH	SPE CO Detectors	N[a] Kerosene Heat On: A. Mean 30, 7.4 ppm; Maximum 30, 11.5 ppm. N Kerosene Heat Off: 37, 1.5 ppm; 37, 1.5 ppm. [a]N=Number of sampling days or number of samples analyzed.
Proctor, (1989)	UK	Offices (10)	Not Given	Mechanical	Electrochemical Detector, 1 sample/minute	(ppm): Offices(S) CO Range 0.5 - 5, CO A. Mean 1.4; Office(NS) 0.7 - 4, 1.2; Trains (S) 1 - 2.2, 1.6; Trains (NS) 0.5 - 2.9, 1.3
		Train Comp.(20) (10S, 10NS)	app. 75%	Not Given		
Proctor, et al. (1989a)	UK	Betting Shops (6)	Not Given	Not Given	Electrochemical Detector	N: Indoor Smoking 11, Range (ppm) 3.6-9.4, A. Mean 5.1; Indoor N-Smoking 2, 2.8-3.4, 3.1; Outdoor 16, 2.8-9.0, 4.4
Proctor, et al. (1989b)	UK	Office Building (1)	26 m^2/person	Not Given	Electrochemical Detector, five 1 hr continuous samples	Smoking Mean - 1.4 ppm; Median - 1.1 ppm; Non smoking Mean - 1.2 ppm; Median - 1 ppm
Sterling & Mueller (1988)	Canada	Office Buildings (2)	.73-1.8/10m^2	1)Mechanical Air Recirc. 2)Natural, No Recirc.	Electrochemical Analyzer, 3-4 min. samples, 6/location	Building(s): Smoking Cafeteria 1&2, A. Mean (ppm) 3.9; Non Smoking Cafeteria 1&2, 2.6; Non Smoking Offices 1, 1.8; Non Smoking Offices 2, 1.35
Sterling, (1988)	Canada	Office Building	.79/10m^2	Forced Air; recirculation Min. 20 cfm/ person fresh air	Electrochemical Analyzer, 3-4 min. samples, 3/location	A. Mean (ppm): Smoking Prohibited 2.1; Smoking Permitted 2.5; Designated Smoking 4.2
Sterling, et al. (1988)	North Am.	Offices	Not Given	Not Given	Not Given	CO (ppm): N 241, Range ND - 245, Median (ppm) 2.65
Thomas, et al. (1989)	USA	Industrial Cafeteria	30±9 people 560 m^3	8.8 ACH 5,400 CFM	Electrochemical Sensor, 120 samples/day for 12 days	Average Concentration (ppm): Lunchtime 0.9 ± 0.4; Background 0.6 ± 0.2
Turner, et al. (1991)	USA	Offices (585)	126.5 ft^2/ person	Not Given	Electrochemical Detector, 10 readings/hour.	N: Smoking 331, CO (ppm) A. Mean 3.40; Non Smoking 254, 3.13; Total 585, 3.29
Yuill & Comeau (1989)	Canada	Homes (76)	Not Given	0.29 ACH (0.0-1.35)	CO Instrument	N: Living Room 76, A. Mean (ppm) 0.7, Range (ppm) 0.0 - 4.0; Basement 69, 0.7, 0.0 - 4.0; Bedroom 73, 0.4, 0.0 - 3.0

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Table 3. Nicotine measured under realistic conditions.

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations/Comments
Chuang, et al. (1988)	USA	Homes (8)	Not Given	Not Given	Pump w/XAD-4 Sorbent 2 - 8 hr samples in living room	Home # / Nicotine ($\mu g/m^3$): 1NS 0.17; 2S 15; 3S 1.7; 4S 29; 5S 45; 6S 4.1; 7NS 0.02; 8NS 0.06; 9S 19; 10NS 0.08
Coultas, et al. (1990a)	USA	Workplace (15)	Not Given	Not Given	Personal Pump w/ Sodium bisulfate filter, 6.5 hr samples	Males: Hospital n=2, A. Mean 28; Offices n=2, 4.85; Barber Shop n=2, 8.85; Restaurant n=1, 45; Retail Store n=1, 6.9. Females: Hospital n=3, 22.7; Offices n=3, 33.97; Public Trans. n=1, 0.0
Coultas, et al. (1990b)	USA	Homes (10)	Not Given	Not Given	Pump w/Sodium Bisulfate filter, 10 samples/home	Mean Range 0.6 - 6.9 $\mu g/m^3$ (100 samples)
Crouse, et al. (1988)	USA	Restaurants (37)	Not Given	Not Given	PASS Unit w/XAD-4 Sorbent, 1 hr sample	Restaurants: n=37; Range ($\mu g/m^3$) 1.6 - 34.7; A. Mean ($\mu g/m^3$) 8.6; G. Mean ($\mu g/m^3$) 5.3 ± 2.4
Crouse & Carson (1989)	USA	Offices (32) Restaurants (36)	Not Given	Not Given	PASS Unit w/XAD-4 Sorbent	Offices ($\mu g/m^3$): G. Mean 3.8, Range 1.2 - 24.3. Restaurants ($\mu g/m^3$): G. Mean 4.1, Range 1.0 - 36
Crouse & Oldaker (1990)	USA	Restaurants (21)	Not Given	Not Given	PASS Unit & Personal Pump w/XAD-4 Sorbent Min. 1 hr sample for four months.	PASS Unit / Personal Pump: Mean ($\mu g/m^3$) 6.3 / 4.3; Median 4.2 / 2.9; Range 0.3 - 24.8 / 0.3 - 24
Eudy, et al. (1987)	USA	Restaurant	Not Given	Not Given	Pump w/XAD-4 Sorbent (12) 4 hr samples during (5) 48 hr sample runs.	Nicotine ($\mu g/m^3$): Range 0.29 - 11.5; A.Mean 2.1
First (1983)	USA	Public Places	Various	Not Given	Pump w/Potassium bisulfate filter	Site / Avg. Conc. ($\mu g/m^3$): Chamber1 13.9 - 1 cig. smoked; Chamber2 13.9 - 1 cig. smoked; School cafeteria1 5.5 - no smokers; School cafeteria2 2.7 - 2-3 smokers; Tavern1 6.3 - 1-5 smokers; Tavern2 9.4 - 2-3 smokers; Tavern3 15.9 - mostly 1 smoker; Bus Terminal ---- - 50-100 people, 1-5 smokers; Fast Food Restaurant 30.0 - 1-3 smokers during sampling; Sm. Sitdown Rest.1 12.0 - 15 diners, 4 smokers; Sm. Sitdown Rest.2 16.3 - 23 diners, 1 smoker
Henderson, et al. (1989)	USA	Homes 15 w/Smokers 12 w/o Smokers	Not Given	Not Given	Pump w/Sodium Bisulfate Filter 5pm-7am @ 2 days	Average Concentration ($\mu g/m^3$): Smoking Homes 3.74; Non smoking Homes 0.34

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Table 3. Continued.

IT Corp. (1987)	USA	Offices (38) Restaurants (36)	Not Given	Not Given	Pump w/XAD-4 Sorbent 1 Hr. Samples	Offices ($\mu g/m^3$): Range nd - 30; A. Mean 6. Restaurants ($\mu g/m^3$): nd - 12; 4. (Offices & Restaurants sampled had no smoking restrictions)
Jenkins, et al. (1988)	USA	Restaurants (36)	Not Given	Not Given	Personal Pump w/ Tenax Sorbent. 1 hr samples	Nicotine ($\mu g/m^3$): Range 0.5 - 37.2; A. Mean 5.78
Lofroth, et al. (1989)	USA	Tavern	5 - 25 $180m^3$	Not Given	Pump w/ filter 3 & 4 hr Samples	1st Study (3hr): 71 $\mu g/m^3$. 2nd Study (4hr): 60 $\mu g/m^3$
McCarthy, et al. (1987)	USA	Homes (81) 68S, 13NS	Not Given	Not Given	Pump w/ Sodium bisufate filter, Personal & Area Samples	Mean / Median / Range ($\mu g/m^3$): Personal (NS) 0.3 / 0.2 / 0.0 - 1.0; Personal (S) 2.5 / 1.9 / 0.1 - 12.0; Home (NS) 0.1 / 0.0 / 0.0 - 1.6. (Personal samples done on children 8-11 yrs old)
Miesner, et al. (1989)	USA	Public Buildings (11)	Not Given	Not Given	Pump w/Sodium bisulfate filter	n / A. Mean ($\mu g/m^3$): Bar (S) 3 / 3.7; Bar/Rest.1 (S) 2 / 7.55; Bar/Rest.2 (S) 2 / 7.85; Subway St. (NS) 1 / 1.0; Hospital (S) 1 / 1.6; Clinic 1 / 17.1 (Des. Smoking Area in NS Building); Office Bldg1 (S) 1 / 0.6; Office Bldg2 (NS) 1 / 2.0 (Smoking room directly below); Office Bldg3 (NS) 1 / 0.4; Office Bldg4 (S) 2 / 3.15; Office Bldg5 1 / 26.5 (Des. Smoking Area in NS Building)
Oldaker, et al. (1988)	USA	Offices (46) Restaurants (49)	Not Given	Not Given	Pass Unit w/XAD-4 Sorbent	Offices ($\mu g/m^3$) / Restaurants ($\mu g/m^3$): G. Mean 3.3 / 4.5; A. Mean 4.3 / 6.2; Range 1.0 - 16.3 / 0.7 - 15.6
Oldaker, et al. (1990)	USA & Canada	Offices & Restaurants (4 Cities)	Min. 2 people/office 1 smoker	Not Given	PASS Unit w/XAD-4 Sorbent Tube.	Offices ($\mu g/m^3$) / Restaurants ($\mu g/m^3$): Range (n=156) 0 - 69.7 / (n=170) 0 - 23.8; Mean 4.8 / 5.1
Proctor (1989)	UK	Offices (10) Train Compartments (20)	Varied 75%	Mechanical Not Given	PASS Unit w/XAD-4 Sorbent, 1 hr samples.	Offices (S) / Offices (NS) / Train (S) / Train (NS) ($\mu g/m^3$): Range 0.6 - 26 / 0.1 - 2.1 / 0.6 - 49.3 / 0.5 - 21.2; A. Mean 6 / 0.6 / 15.3 / 4.5
Proctor, et al. (1989a)	UK	Betting Shops (6)	Not Given	Not Given	PASS w/Tenax Sorbent	n / Range ($\mu g/m^3$) / A. Mean ($\mu g/m^3$): Smoking 11 / 3 - 57 / 19.36; Non Smoking 2 / 0.4 - 2 / 1.2; Outdoor 3 / 0.3 -0 .4 / 0.33
Proctor, et al. (1989b)	UK	Office (1)	265 ft^2/ person	Not Given	Pump w/XAD-4 Sorbent	Mean ($\mu g/m^3$) / Median ($\mu g/m^3$): Smoking 6 / 3.1; Non Smoking 0.6 / 0.6

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Table 3. Continued.

Schenker, et al. (1987)	USA	RR Workers Office, Repair Shop, Outdoors	Not Given	Not Given	Personal Pumps w/Sodium Bisulfate Filter (2 Days)	Mean Concentration ($\mu g/m^3$) Office (n=12) 10.2 ± 2.2 Repair (n=13) 5.8 ± 3.4 Outdoor (n=73) 0.4 ± 0.1
Sterling et al. (1988)	USA & Canada	Offices (32)	Not Given	Not Given	Not Given	Range ND - 43.7 $\mu g/m^3$ Median - ND
Sterling & Mueller (1988)	Canada	Office (1) N-Smoking	.79/10m^2	Forced Air; Recirculation from (S) area	Personal Pump w/XAD-4 Sorbent, 2-8 hr Samples	Range ($\mu g/m^3$) nd - 1
Thomas, et al. (1989)	USA	Industrial Cafeteria	30 ± 9 560 m^3	8.8 ACH 2900 cfm OA 2500 cfm RA	Pump w/XAD-4 Sorbent 2 hr. samples for 14 days (11:30-1:30)	Lunchtime / Background Avg. Conc. ($\mu g/m^3$) 5.1 ± 1.6 / 0.14 ± 0.03 (Average smoking rate during sampling was 26±6 cig/hr)
Turner, et al. (1991)	USA	Offices (585)	126 ft^2/ person	Not Given	Personal Pump w/XAD-4 Sorbent, 1 hour samples.	Nicotine- A. Mean ($\mu g/m^3$) Smoking 6.6 Non Smoking 0.17 Total 3.84
Vaughan & Hammond (1990)	USA	Office	Not Given	Not Given	Passive (M-F) & Active (W) on sodium bisulfate filters.	A.Mean Pre Smoking Policy ($\mu g/m^3$) / Post Smoking Policy NS desks (n=13) 2.45 / 0.3 Snack Bar (n=3) 11.3 / 85.4 (Designated Smoking) Cafeteria (n=6) 4.5 / 5.3 S Desks (n=6) 10.7 / ....

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Table 4. Nitrogen dioxide measured under realistic conditions (ppm = 1 900 µg/m³; ppb = 1.9 µg/m³).

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations/Comments
Berwick, et al. (1989)	USA	Homes (72)	Not Given	Not Given	Passive tubes, 3 locations/house, 2 week samples	NO_2, µg/m³ 1+2: Kitchen N=6 98.50; Living Room N=6 76.00; Bedroom N=6 104.75; House Ave. N=6 90.08 1 only: Kitchen N=49 41.07; Living Room N=49 43.40; Bedroom N=49 38.33; House Ave. N=49 40.93 2 only: Kitchen N=13 40.92; Living Room N=13 24.85; Bedroom N=13 28.54; House Ave. N=13 31.43 None: Kitchen N=4 6.40; Living Room N=4 6.23; Bedroom N=4 5.19; House Ave. N=4 5.94 1 = Kerosene heater 2 = Gas stove
Brauer, et al. (1990)	USA	Homes (11)	Not Given	Not Given	Passive samplers Triethanolamine Colorimetric 24 hr. indoor, 48 hr. outdoor	NO_2, ppb Indoor N=30 Mean=17 Min.=7 Max.=36 Outdoor N=30 Mean=15 Min.=5 Max.=26
Dumont, (1986)	Canada	Homes (46)	Not Given	Varied	Passive samples, 1 week, 1 sample/house	NO_2: Wood stove, smoke N=9 A. Mean (ppb)=5.6; Wood stove, no smoke N=21 5.1; No wood stove, smoke N=4 5.3; No wood stove, no smoke N=12 3.5
Good, et al. (1982)	USA	Homes (90)	Summer: Avg. No. Smokers S home 2.2, NS home 2.7; Avg. No. NSmokers S home 1.3, NS home 0.3 Winter: Avg. No. Smokers S home 2.0, NS home 2.7; Avg. No. NSmokers S home 1.4, NS home 0.2 vent. rates not given	Palmes personal sampler, 7 day, kitchen, betroom, living room.	NO_2, means, µg/m³ Elec. > 20 N=8 Kitchen Sum. 15.6 Win. 21.3; Living Room Sum. 16.5 Win. 23.5; Bedroom Sum. 14.0 Win. 21.3 Gas > 20 N=8 Kitchen Sum. 76.3 Win. 156.6; Living Room Sum. 66.9 Win. 112.2; Bedroom Sum. 48.4 Win. 96.4 Elec. ≤ 20 N=3 Kitchen Sum. 11.8 Win. 20.3; Living Room Sum. 12.4 Win. 19.6; Bedroom Sum. 10.7 Win. 17.5 Gas ≤ 20 N=3 Kitchen Sum. 87.0 Win. 219.6; Living Room Sum. 47.1 Win. 117.4; Bedroom Sum. 38.7 Win. 97.8
						NO_2, µg/m³
						Room / Season / Smoke / N / Mean / Max / Min Living Room: Summer NS 54 12.4 86.5 -2.5; Summer S 38 16.5 40.8 -0.4; Winter NS 49 17.5 36.6 5.7; Winter S 38 21.3 49.6 -1.6 Bedroom: Summer NS 54 10.7 66.9 -2.7; Summer S 38 14.0 42.7 -0.6; Winter NS 50 20.3 57.1 5.3; Winter S 38 21.3 54.3 1.4 Kitchen: Summer NS 54 11.8 72.0 -3.4; Summer S 38 15.6 44.7 0.5; Winter NS 49 19.6 44.5 5.7; Winter S 38 23.5 65.6 1.4 Outside: Summer NS 54 21.3 70.5 1.1; Summer S 38 22.6 54.5 6.3; Winter NS 48 52.3 99.9 18.7; Winter S 35 50.0 91.3 8.9
Hollowell and Miksch (1981)	USA	Office (1)	Not Given	Not Given	One week	NO_2 - 60 µg/m³, 30 ppb

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Table 4. Continued.

Hosein, et al. (1985)	Canada	Homes (52)	Not Given	Not Given	NaOH impinger	NO_2 $\mu g/m^3$, Geometric means

	Air Cond.		No Air Cond.	
	N	NO2	N	NO2
Gas Stove	4	175.1	7	182.1
Elec. Stove	12	70.9	29	81.8
No Gas	Summer		Winter	
	N	NO2	N	NO2
Smoke	29	76.1	29	82.6
No Smoke	12	74.5	12	75.7

Marbury, et al. (1988)	USA	Homes (144)	Not Given	Not Given	Passive sample tubes 2, 2 week samples, 3 samples/home	NO_2, means and range, ppb

	Gas stove		Elec. stove	
	1	2	1	2
Outside	19.1	20.3	14.1	19.6
	(5.2-26.7)	(6.9-31.6)	(5.1-24.3)	(5.1-30.1)
	N=36	N=38	N=38	N=28
Activity Room	41.3	39.3	7.8	7.0
	(8.4-168.7)	(7.0-135.9)	(2.0-20.9)	(1.3-22.7)
	N=81	N=74	N=59	N=53
Bedroom	33.1	30.9	7.0	6.2
	(4.4-167.1)	(4.0-140.4)	(1.6-32.5)	(1.1-22.4)
	N=82	N=75	N=60	N=56

1 = 1st cycle of samples 2 = 2nd cycle of samples

Morey and Jenkins (1989)	USA	Offices (7) (problems reported)	Not Given	Not Given	Triethanolamine tube 50-200 ml/min., colorimetric	NO_2, ppm

Bldg.	Outdoor, roof	Indoor
E	<0.07	<0.06-0.10
E	----	0.2-0.3
F	0.04	0.20
G	0.05	0.09-0.10
H	0.10	<0.07-0.09
I	0.10	0.03-0.16
J	<0.02	<0.02-0.20
K	<0.02-0.05	<0.03-0.60
K	0.03-0.08	0.04-0.70

Moschandreas, et al. (1990)	USA	Homes (18) w/gas furnaces	Not Given	Not Given	Portable Chemi-luminescence det., 4 samples ≤ 15 min.	

NO_2	Appliance Room (ppb)		Control Room (ppb)	
	Mean	Range	Mean	Range
Furnace Off	29	3 - 33	32	7 - 40
Furnace On	40	3 - 58	42	4 - 54

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Table 4. Continued.

Petreas, et al. (1988)	USA	Mobil Homes (312)	Not Given	Not Given	Palmes tubes, 3 sites/house, one week samples	NO_2, ppb

		Room	N	A. Mean	G. Mean
Summer, all		Kitchen	311	20.73	16.92
		Bedroom	312	14.64	11.71
		Outdoor	30	11.64	8.95
	gas	Kitchen	263	22.89	20.25
		Bedroom	265	15.99	13.51
		Outdoor	25	11.20	8.39
	elec.	Kitchen	47	8.98	6.18
		Bedroom	46	7.77	5.14
		Outdoor	5	13.78	12.33
Winter, all		Kitchen	254	26.56	21.09
		Bedroom	254	18.67	15.10
		Outdoor	27	22.61	19.16
	gas	Kitchen	230	28.68	24.33
		Bedroom	230	19.98	16.77
		Outdoor	23	22.41	18.77
	elec.	Kitchen	23	6.29	5.36
		Bedroom	23	6.07	5.48
		Outdoor	4	23.74	21.52

gas = gas stove elec. = electric stove

			N	A. Mean	G. Mean
Summer	Kitchen	LA	61	36.92	24.26
		Non-LA	250	19.26	15.66
	Bedroom	LA	60	22.31	19.44
		Non-LA	252	12.97	10.27
Winter	Kitchen	LA	46	34.75	30.52
		Non-LA	208	24.76	19.55
	Bedroom	LA	48	25.74	21.26
		Non-LA	206	17.03	13.98

LA = Los Angeles basin Non-LA = Not in LA

Spengler, et al. (1987)	USA	Homes	Not Given	Not Given	Palmes Passive Sampler	NO_2	Gas Home (ppb)			Electric Home (ppb)		
							N	Mean	SD	N	Mean	SD
						Fall	160	27.6	10	68	11.8	2.5
						Summer	142	25.2	6.6	68	14.4	2.5
						Winter	166	24.3	5.4	70	17.1	3.5

Sterling, et al. (1988)	USA & Canada	Offices	Not Given	Not Given	Not Given		N	Median	Min, Max,
						NO_2	49	ND	ND 0.1 ppm
						NO_x	40	ND	ND 26.3 ppm

Yocom, (1982)	USA	Homes (9)	Not Given	Not Given	Palmes tubes, 4 week	NO_2		Gas stove (5)	Elec. Stove (4)
					Mean values ($\mu g/m^3$)	Fixed,	Outside	17.1 $\mu g/m^3$	16.9 $\mu g/m^3$
							Kitchen	59.2	15.7
							Bedroom	37.3	14.5
						Personal,	Husband	36.3	19.8
							Wife	40.8	16.7
							Child	45.2	8.7

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Table 5. Formaldehyde measured under realistic conditions (ppm = 1 230 µg/m³).

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations/Comments
Dumont, (1986)	Canada	Homes (46)	Not Given	0.21 ach, ave.	Passive badges 2 samples/house 1 week/sample	Formaldehyde (ppm) Mean 0.097 Median 0.091 Range 0.03-0.24
Girman, et al. (1989)	USA	Office Building (52,000 sq. ft.)	Not Given	Mechanical	Midget impingers chromotropic acid analysis, formaldehyde	Pre-Bake Out (µg/m³) / Post-Bake Out (µg/m³): 1st Floor 51 / 65; 2nd Floor 32 / 38; Plenum 34 / 38; Outdoor BD / BD
Grot, et al. (1991)	USA	Office (1)	230 ft²/ Person	Not Given	Sodium bisulfite impregnated filter	Formaldehyde 0.02-0.06 ppm
Hedge, et al. (1990)	USA	Office Buildings (2)	Not Given	Not Given	EPA Method IO-11 3 hr samples	Mean Formaldehyde (ppm): AM / PM. SP 0.023 / 0.019 (SP=Smoking Prohibited); SR (Office) 0.008 / 0.012 (SR=Smoking Restricted); SR (Smoking) 0.018 / 0.023
Hollowell and Miksch (1981)	USA	Home (1) Office (1)	Not Given	0.4 ach	Not Given	Formaldehyde in new home: Unoccupied, no furniture 80± 9% µg/m³; Unoccupied, with furniture 223± 7% µg/m³; Occupied, day 261±10% µg/m³; Occupied, night 140±31% µg/m³; Outside <20 µg/m³. Aldehydes in an office building (µg/m³): Formaldehyde 49. Formaldehyde from various indoor environments: Mobile homes (2), Pa. 0.1-0.8 (Mean 0.36); Mobile homes w/ complaints (Wash.) 0-1.77 (Mean 0.1-0.44); Mobile homes w/ complaints (Minn.) 0-3.0 (Mean 0.4); Mobile homes w/ complaints (Wisc.) 0.023-4.2 (Mean 0.88)
Lofroth, et al. (1989)	USA	Tavern	5-25 people 180 m³	Not Given	Pump w/sorbent 3 & 4 hr samples HPLC Analysis	1st Study 3 Hr / 2nd Study 4 Hr (µg/m³): Formaldehyde 104 / 89

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Table 5. Continued.

Proskiw, et al. (1989)	Canada	Homes (20)	Not Given	see results	Passive dosimeter One week	House type / Formaldehyde (ppm) / Vent. rate (ach)

R-2000	N	Mean	Median	N	Mean	Median
Mar 86	6	0.061	0.060	6	0.28	0.26
Aug 86	16	0.058	0.057	-	----	----
Oct 86	16	0.080	0.072	16	0.30	0.29
Feb 87	16	0.064	0.061	16	0.43	0.45
Total	54	0.064	0.061	37	0.35	0.36
Conventional						
Mar 86	4	0.078	0.077	4	0.16	0.44
Aug 86	4	0.067	0.065	-	----	----
Oct 86	3	0.090	0.086	4	0.15	0.17
Feb 87	4	0.067	0.060	4	0.20	0.18
Total	15	0.074	0.066	12	0.17	0.17
Smoking homes		0.065	0.063			
Nonsmoking homes		0.068	0.063			

Quackenboss, et al. (1989b)	USA	Homes (151)	Not Given	Not Given	Passive Samplers Sodium bisulfite One week, 3 sites/house	Building type / Evap. Cooler / Mean µg/m³ / N

Building type	Evap. Cooler	Mean µg/m³	N
Single fam.	Yes	27	50
	No	37	52
	Total	32	102
Mobile/trailer	Yes	36	6
	No	68	10
	Total	49	10
Apt./Condo.	Yes	25	5
	No	51	24
	Total	47	29
All types	Yes	27	62
	No	43	83

Sterling, et al. (1988)	USA & Canada	Offices (259)	Not Given	Not Given	Not Given	Formaldehyde ND - 1.9 ppm; 0.01, median

Stock (1987)	USA	Homes (41)	Not Given	Not Given	Passive badges one week samples two samples/home	Formaldehyde (ppm)

Area	N	Mean	Range
Clear Lake	27	0.07	0.03-0.15
Sunnyside	14	0.10	0.06-0.18

Smoking (cig/day)	N	Mean
<1	26	0.07
1-4	4	0.13
5-10	6	0.07
≥ 20	7	0.07

Yocom (1982)	USA	Homes (2)	Not Given	Not Given	Not Given	House / Formaldehyde (µg/m³)

House	Range	Average	Outdoor
ISUERH	34-75	42	<9
ERHH	54-182	120	<12

Yuill & Comeau (1989)	Canada	Homes (50)	Not Given	0.29, Mean ach 0.00-1.35	Passive bubbler colorimetric 2 hour samples	Formaldehyde (ppm)

Room	N	Ave.	Max.	Min.
Living room	50	0.090	0.261	0.000
Basement	45	0.088	0.235	0.000
Bedroom	49	0.092	0.285	0.000

Source: https://www.industrydocuments.ucsf.edu/docs/kgnm0000

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Table 6. Benzene measured under realistic conditions (ppb = 3.2 μg/m³).

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations/Comments
Bayer & Black (1987)	USA	Offices	Not Given	Mechanical	Personal Pump w/Tenax, 4 hr samples(3S,3NS)	Benzene: Smoking 2.0ppb; Non Smoking 1.2ppb
Chan, et al. (1990)	Canada	Homes (12)	Not Given	Not Given	Tenax/Charcoal 2 outdoor, 4 indoor samples each, 90 min. samples, 5-50 liters/ sample	Frequency, Range, and Avg. (μg/m³) Outdoors/Indoors 12 Homes Ambient Air (Nov/Dec): F 12, Range 1-11, Avg. 7.3 Indoor Air: F 12, Range 5-59, Avg. 14.8 Frequency, Range, and Avg. (μg/m³) Outdoor/Indoors 6 Homes Ambient Air (Feb/Mar): F 6, Range 2-8, Avg. 6.0 Indoor Air: F 6, Range 7-15, Avg. 10.6
Girman, et al. (1989)	USA	Office Building (52,000 ft²)	Not Given	Mechanical	Pump w/Tenax Sorbent, GC/MS	Concentrations (μg/m³) Pre-Bake-Out: 1st Fl. 2.8; 2nd Fl. 3; Plenum 3; Roof 1 Post-Bake-Out: 1st Fl. 0.8; 2nd Fl. 1.5; Plenum BD; Roof BD (BD = Below Detection)
Lewis (1991)	USA	Homes (10)	Not Given	.2-.8 ACH	SS Canister 12 hr samples, GC/MS	Avg. Indoor Conc. from OUTdoor Sources and Indoor Souces (ppbC) Benzene: R05 OUT 11, IN 2; R08 OUT 17, IN -1; R11 OUT 20, IN 2; R14 OUT 11, IN 1; R17 OUT 14, IN 0; R20 OUT 15, IN 1; R26 OUT 30, IN -1; R29 OUT 13, IN 2; ALL OUT 15, IN 1
Lofroth, et al. (1989)	USA	Tavern	5 - 25 people 180 m³	Not Given	Stainless steel canister, GC/MS	Benzene: first Study (3hr) Indoor 27, Outdoor 6; Second Study (4hr) Indoor 21, Outdoor 8 (μg/m³)
Pleil, et al. (1986)	USA	Homes (26)	Not Given	Not Given	Summa Cannisters GC/FID,ECD	Indoor Air (PPBV): Summer Data 15 Samples: # Obs. 15, Mean 7.6, Range 0.39-48; Winter Data 16 Samples: # Obs. 16, Mean 4.8, Range 0.53-23.6 Outdoor Air: Summer & Winter 6 Samples Each: # Obs. 12, Mean 0.57, Range 0.33-0.77 Benzene
Proctor (1989)	UK	Offices (10) Trains (20)	Not Given	Not Given	Pump w/Tenax Sorbent, 1 hr. samples,	A. Mean, Median, Range (μg/m³) Benzene: 6, 3.1, 0.6 - 26; 11.8, 11.6, 0.9 - 28.6 Offices(NS): Benzene 12, 10, 3 - 31 Train(NS): 7.4, 5.1, 2.9 - 29.3

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Table 6. Continued.

Proctor, et al. (1989a)	UK	Betting Shops (6)	See chart	Not Given	Tenax IA, 3 l/hr. briefcase, GC/MS	Compound	N	Site/smoke	Pop/smokers	Qty. Mean ($\mu g/m^3$)									
						Benzene	3	A/S	20/5	14.3									
							2	B/S	10/2	14									
							2	C/S	7/3	21									
							2	D/S	15/5	18.5									
							2	E/S	10/2	18.5									
							1	E/Outside	Hvy. Traffic	22									
							2	F/NS	11/0	9.5									
							2	F/Outside	Med. Traffic	15									
Proctor, et al. (1989b)	UK	Office (1)	265 ft^2/person	Not Given	Tenax, 10 ml/min. GC/MS, pump Concs in $\mu g/m^3$	Compound	Smokers' Office A. Mean	Smokers' Office Median	Nonsmokers' Office A. Mean	Nonsmokers' Office Median									
						Benzene	13	8	12	10									
Proctor, et al. (1991)	UK	Homes & work	Varied	Varied	Personal sampler 24 hour samples, 52 women														
Compound	Smoke/Work			Smoke/No work			No smoke/Work			No smoke/No work			All Subjects						
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range				
Benzene	15.7	13.3	3.2-48.7	21.6	13.4	5.2-103	60.7	15.5	0.7-510	13.2	10.4	0.2-32.1	26.5	12.8	0.2-510				
Sheldon, et al. (1988b)	USA	Hospital (1) Nursing Home (2) Offices (3)	Not Given	Not Given	Pump w/Tenax 12 hr sample GC/MS														
	Mean Concentration (ng/L)																		
	Martinsburg, WV			Fairfax, VA		Worcester, MA		Washington, DC	Cambridge, MA	Martinsburg, WV									
	Hospital (new)[a]			Office (new)[b]		Nursing Home (new)[c]		Office (old)	Office/School (old)	Nursing Home (old)									
	Trip 1 (7/84)	Trip 2 (10/84)	Trip 3 (8/85)	Trip 1 (1/85)	Trip 2 (4/85)	Trip 1 (4/85)	Trip 2 (8/85)	Trip 1 (8/84)	Trip 1 (2/85)	Trip 1 (7/84)									
Benzene	1.55	2.13	2.88	2.74	4.95	1.70	2.44	5.61	4.50	3.13									
Sheldon, et al. (1988a)	USA	Office Building (1)	Not Given	Not Given	Pump w/Tenax 12 hr sample GC/MS														
							Concentration ($\mu g/m^3$)												
							Indoors[a] July	Sept.	Dec.	Outdoor[b] all trips									
						Benzene	5	7	7	3									
([a]Mean of six 12-hr avgs. at 5 indoor locations. [b]Mean of 18 12-hr avgs. at one outdoor location.)																			
Sheldon, et al. (1990)	USA	Homes (12)	16 individuals	Not Given	24 Hour Samples w/Tenax, GC/MS														
							Mean Concentration (ng/l) ± S.D.												
							Outdoor (n=4)	Indoor (n=12)	Personal (n=8)										
						Benzene	12±8.8	8.7±2.6	11±4.0										
Sterling, et al. (1988)	USA & Canada	Offices (see table for numbers)	Not Given	Not Given	Not Given	Compound	N	Range	Median										
						Benzene	27	ND-1.4 mg/m^3	trace										

[a]Building completed approximately 34 weeks before first monitoring trip.
[b]Building completed approximately 1 week before first monitoring trip.
[c]Building completed approximately 4 weeks before first monitoring trip.

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Table 6. Continued.

Wallace, (1986)	USA	Various (TEAM study)	Not Given	Not Given	Personal and Outdoor samples	Population-Weighted Arithmetic Mean Exposures (24 Hour Samples) $\mu g/m^3$

Sites	Benzene PE[a]	Benzene Out
New Jersey		
Fall 1981	28	9
Summer 1982	NC[b]	NC
Winter 1983	NC	NC
N. Carolina	9	12
N. Dakota	NC	NC
California		
LA:Winter84	18	16
LA:Spring84	9	4
CC:Spring84	7	2

[a]Personal Exposure

[b]Not Calculated--did not meet quality control criteria.

Wallace, et al. (1987)	USA	Homes	Not Given	Not Given	Personal Pumps w/ Tenax sorbent, 12 hr samples GC/MS	Personal Air Exposures-Unweighted Geometric Mean

	n		Benzene	
	S	NS	S	NS
NJ(F)	153	188	18	11
NJ(S)	69	75	NR	NR
NJ(W)	24	22	NR	NR
LA(W)	29	85	18	14
LA(SP)	11	40	8	7
AP(SP)	19	49	8	7
Overnight Indoor Conc.-Weighted Geometric Mean ($\mu g/m^3$)				
NJ(F)	252	94	16	8.4
NJ(S)	111	44	NR	NR
NJ(W)	37	12	NR	NR
LA(W)	56	58	17	11
LA(SP)	23	28	4.8	4.5
AP(SP)	35	33	4.9	4.4

F=Fall S=Summer W=Winter SP=Spring

Weschler, et al. (1990)	USA	Office Building	Not Given	Not Given	Passive Samplers 4 Periods During 1 Year	VOC ($\mu g/m^3$) Building 2 on 4th Floor During Four Sampling Periods

	6/25/87-7/16/87	9/9/87-10/1/87	11/6/87-12/4/87	3/3/88-3/15/88
Benzene	ND	ND	1.3	ND

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Source: https://www.industrydocuments.ucsf.edu/docs/kgnm0000

Table 7. Nitrosamines measured under realistic conditions.

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations/Comments			
Hoffman, et al. (1987)	USA & Austria	Various	Not Given	Not Given	Pump w/liquid traps, GC/TEA, 1-4 hr continuous samples		NDMA	NDEA	($\mu g/m^3$)
						Train-Bar	0.11-0.13	ND	
						Bar	0.24	ND	
						Sports Hall	0.09	ND	
						Betting Parlor	0.05	ND	
						Residence, NS	<.003	ND	
						Office	0.03	0.03	
						Conference Room	0.02-.033	0-.02	
						Work Room	0.023	0	
						Restaurant	0-0.05	0	
						Dance Hall	0.07	0.2	

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Room size	Room Type	# of People	Tobacco Consumed	NDMA (ng/L)	NDEA (ng/L)
Stehlik, et al. (1982)	Austria	Offices Restaurants Bars	see chart	Not Given	Pump w/liquid traps, GC/TEA, 1-4 hr continuous samples	$207m^3$	Working Room	7	Continuous (2hr)	0.024	BD
						301	Conference Room	15	26 cig., 1 pipe 6 cigarillos (2hr)	0.031	BD
						70	Office	6	27 cig. (2hr)	0.03	0.03
						50	Sm. Conf. Room	12	37 cigs., 4 pipes 3 cigars (2hr)	0.02	0.02
						120	Suburban Rest.	20	20-30 cigs, 2 pipes (2hr)	BD	BD
						160	Vienna Rest.	23	20 cigs., (1hr)	0.01	BD
						180	Vienna Rest. 2	25	25-30 cigs., (1hr)	0.04	BD
						160	Vienna Rest. 3	23	15-20 cigs., (1hr)	0.05	BD
						320	Dancing Bar	30-70	Not Determ.(4hr)	0.07	0.2

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Table 8. PHA measured under realistic conditions.

Author & Date	Country	Building Type	Occupancy	Ventilation	Sampling	Concentrations/Comments

U.S. EPA (1988) — USA — Homes (8) — Not Given — Not Given — Pump w/XAD-4 Sorbent, GC/MS 8 hr Samples

HOME (ng/m^3) (Selected PAH measured in living rooms)

Compound	1NS	2S	3S	4S	5S	6S	7NS	8NS	A. Mean 9	10S
Naphthalene	800	1100	1100	1100	2200	4200	1800	880	1940	1160
Acenaphthylene	18	37	17	48	120	59	10	8.9	56	12
Phenanthrene	71	87	80	200	210	110	59	86	137	72
Fluoranthene	7.6	8.6	6.5	19	23	6.4	7.2	12	13	9
Pyrene	4.6	5.2	4.0	11	17	9.5	5.6	7.4	9	6
Benzo(e)pyrene	0.74	3.2	1.3	3.7	10	6.5	0.68	1.4	5	1
Benzo(a)pyrene	0.28	1.2	0.34	1.4	3.3	1.4	0.31	0.83	1.5	0.47
Quinoline	9.4	240	76	480	1100	300	23	9.1	439	15.8
Isoquinoline	21	140	34	300	620	170	35	16	255	74

Daisey, et al. (1989) — USA — Homes (7) — Not Given — 0.13-0.89 ACH — Pump w/Teflon coated fiberglass filter, 48 hr samples

House	Wood burning	PAH (ng/m^3) FLU	PYR	BEP	BBF	BKF	BAP	BGHIP	[illegible]	TOTAL
102	+	0.72	0.47	0.48	0.52	0.24	0.46	1.25	[illegible]	6.1
	-	1.18	0.98	0.41	0.24	0.10	0.17	0.15	[illegible]	3.4
106	+	0.32	0.62	0.65	0.68	0.29	1.24	6.20	[illegible]	13.5
	-	0.58	0.70	0.42	0.11	0.04	0.11	0.33	[illegible]	2.4
108	+	0.96	0.50	0.38	0.40	0.19	0.43	0.55	[illegible]	4.5
	-	0.11	0.03	<0.06	0.04	0.02	0.03	0.08	[illegible]	0.4
203	+	0.81	0.58	0.95	0.51	0.21	0.40	0.75	[illegible]	5.2
	-	0.07	0.14	<0.06	<0.007	0.007	<0.009	<0.01	[illegible]	0.3
204	+	0.16	0.02	0.14	0.10	0.03	0.07	0.12	[illegible]	0.8
	-	0.09	0.22	0.07	0.02	0.01	<0.009	0.02	[illegible]	0.5
208	+	0.65	0.65	1.36	1.22	0.48	1.34	0.87	[illegible]	8.8
	-	0.07	0.05	<0.06	0.009	0.005	<0.009	<0.01	[illegible]	0.2
300	+	0.18	1.53	0.31	0.27	0.09	0.33	0.25	[illegible]	3.4
	-	0.50	0.31	0.43	0.04	0.02	0.02	0.10	[illegible]	1.6

(FLU=Fluoranthene, PYR=Pyrene, BEP=Benzo(e)pyrene, BBF=Benzo(b)fluoranthene, BKF=Benzo(k)fluoranthene, BAP=Benzo(a)pyrene, BGHIP=Benzo(ghi)perylene, IND=Indeno(1,2,3,-cd)pyrene)

Grimsrud, et al. (1990) — USA — Office Buildings (40) — Not Given — Not Given — Gravimetric PM3.0 126 RSP samples analysed for B(a)P

	Mean Concentration B(a)P (ng/m^3)
Non smoking Areas	0.4
Smoking Areas	1.1

Lioy, et al. (1987) — USA — Homes (6) — Not Given — Not Given — PM10 extraction

Home	N	B(a)P G. Mean	Maximum (ng/m^3)
1	14	0.5	4.8
2	13	1.1	4.4
3	14	0.8	2.3
6	13	0.3	1.4

Waldman, et al. (1989) — USA — Homes — Not Given — Not Given — PM10 extraction — BaP Range nd - 8.6 ng/m^3

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receive would provide an independent assessment as to whether these health claims are realistic.

Dose is defined as the amount [illegible]

The dose is a function of the concentration of a substance, the duration of exposure, the rate of respiration, and the percentage of material potentially retained by the lungs.

Concentration: Concentrations of RSPs were determined as the mean difference between nonsmoking and smoking conditions as shown in Table 9.

Duration of exposure: In order to determine the duration of exposure in each of the five categories, data on time activity patterns were needed. Though there were several references available describing studies which performed time/activity surveys of one type or another, there were few that were adequate. The requirements that needed to be met included:

1. Data needed to be American or Canadian
2. Study needed to be of adults
3. Study could not be of select subpopulations
4. Study needed to include most of the entire day.

Five publications met the four chosen criteria (Jenkins et al. 1990; Juster and Stafford 1990; Shaw 1983; Spengler et al. 1985; Szalai et al. 1972). Each author's activity categories were allocated to one of the following locations that were chosen to match exposure categories used for the literature review.

	Location	Exposure Category
[illegible]	[illegible]	Home
[illegible]	[illegible]	Office [illegible]
3.	Public Transportation	Public transportation
4.	Restaurant	Restaurant
6.	Bar	Bar/Taverns
7.	Other, public	Office, workplaces (similar to office environment)
8.	Outdoor	None

Time allocations for each category were then averaged to produce an average day based on the five studies reviewed. Time spent in each category is expressed separately for males, females, employed, and unemployed persons. Time spent in each activity category is expressed in minutes per day and hours per day averaged over seven days per week. If the average day did not add up to 1440 min (24 h), each category was adjusted by the percentage of the error to produce a 24-h day.

There were fewer data available regarding employed/unemployed time activity patterns than for male/female time activity patterns. Because of this, it was necessary to subdivide some authors' categories into more than one of the five chosen for

Table 9. Mean respirable particles µg/m³ in smoking and nonsmoking areas in real-life situations.

		Smoking			Nonsmoking			Diff. in Means: S - NS
Category	# of Studies	N	Mean	Range	N	Mean	Range	
Homes	14	951	49.5	17-212	905	22.3	7-77.1	27.2
Offices and Public Places	24	805	67.7	12-2700	640	45.9	nd-240	21.8
Restaurants	11	257	131.5	nd-685	335[b]	89.7	c	41.8
Bars/Taverns	4	9	103.7	c	c	c	c	103.7[d]
Trains	1	20	216	70.8-325	20	186	63.3-450	30

a - The mean is calculated by weighting the mean values in each study based on sample size and the calculating an overall arithmetic mean. If actual values for nonsmoking or smoking areas were not given, but UVPM values were available, the UVPM values were utilized in obtaining the weighted means. For example, if a total RSP mean value and UVPM mean value were available for a smoking area but not for a nonsmoking area, a nonsmoking area value was obtained by subtracting the UVPM value from the total RSP value.

b - Derived from total RSP-UVPM.

c - No ranges available; no data available.

d - Some of this RSP would be due to sources other than tobacco smoke. If properties are similar to restaurants, this mean would be approximately 48.3.

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Table 10. Carbon monoxide concentrations (ppm) in smoking and nonsmoking areas in real-life situations. Conversion factor: 1ppm = 1.15 mg/m³.

Category	No. of Studies	Smoking N	Smoking Mean	Smoking Range	Nonsmoking N	Nonsmoking Mean	Nonsmoking Range	Difference in Means S - NS
Offices and Public Bldgs.	10	597	2.55	0.1-8.7	275	2.99	0.7-4.0	-0.04
Restaurants	5	127	3.6	0.4-9.0	---	---	---	---
Taverns/Bars	2	5	6.4	-------	---	---	---	---
Trains	2	18	2.2	1.0-5.2	10	1.30	0.5-2.9	0.90
Buses	1	35	6.0	3.7-10.2	---	----	-------	---
Autos	1	---	----	--------	213	11.6	8.8-22.3	---

Homes - Very little information on homes
Yuill et al. (1989); 76 homes, 0.7 mean, range 0-4.0
No data on smoking or nonsmoking.

Table 11. Nicotine concentrations (μg/m³) in smoking and nonsmoking areas in real-life situations.

Category	Smoking No. Studies	Smoking Sample Sites	Smoking Mean	Smoking Range	Nonsmoking No. Studies	Nonsmoking Sample Sites	Nonsmoking Mean	Nonsmoking Range
Offices and Public Bldgs.	14	673	6.2	ND-69.7	5	270	0.3	0.1-2.1
Restaurants	10	390	5.7	0-37.2				
Taverns/Bars Betting Shops	4	17	19.1	3-65.5	1	2	1.2	0.4-2.0
Homes	1	98	3.7	0.1-12.0	3	28	0.29	0-1.0
Trains	1	20	15.3	0.6-49.3	1	20	4.5	0.5-21.2

this review. To do this, the proportion determined from the male/female time activity pattern was used to divide that author's category. For example, time at home for employed and unemployed persons was determined by Spengler et al. (1985) but not divided into waking and sleeping time. The amount of time determined to be spent sleeping in the male/female time allocation was subtracted from Spengler's home time to produce home-awake and home-asleep values for employed/unemployed persons. The time activity patterns calculated from the literature are listed in Tables 12 and 13.

Respiration rates: Respiration rates were taken from Rosenblatt et al. (1982):

1) Adult male, light work—28.6 L/min (1.7 m^3/h)
2) Adult male, resting—7.43 L/min (0.4 m^3/h)
3) Adult female, light work—16.3 L/min (1.0 m^3/h)
4) Adult female, resting—4.5 L/min (0.3 m^3/h).

These figures assume 16 h of rest and 8 h of light work per day, and are in agreement with those from other sources (USEPA 1989).

An average of approximately eight hours per day is spent sleeping. This leaves eight waking hours per day spent at "light work" and eight hours spent "resting". Since no single activity period is likely to be all "light work" or all "resting", the two values were averaged to produce a respiration rate for "awake". These values are as follows:

Male, awake—1.05 m^3/h
Male, asleep—0.4 m^3/h
Female, awake—0.65 m^3/h
Female, asleep—0.3 m^3/h.

Retention efficiency: Retention efficiency for side-stream smoke particles has been reported by Hiller et al. (1982, 1987) to be 11%.

Results of dosimetric calculations

In any exposure situation, the retained dose may be calculated by the following equation:

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Dose = Concentration × duration × respiration rate × % retention.

[illegible] is taken from the time/ac-

Respiration rates are calculated from Rosenblett. The "home, asleep" category is given the resting respiration rate. All other categories are assigned the "awake" respiration rate.

Percent retention is 11% as calculated by Hiller.

Exposure to ETS can come in any number or combination of situations. To estimate the breadth of possible ETS exposures, doses of ETS have been calculated for four different scenarios:

1) Male and female—exposed at home, in restaurants, bars and other public places, but not at work or while traveling. This essentially calculates the ETS exposure one may expect during nonworking hours.

2) Male and female—exposed only at work and while traveling (assume all transportation by train). This will produce a conservative estimate of occupational exposures.

3) Worst case exposure, male and female—exposed at home and while traveling, works in a bar and is also exposed in other public places (assumes use of the average exposure values).

4) Employed vs. unemployed males—exposed in all facets of life, employed person works in office environment. Employed and unemployed females would be essentially the same but with different respiration rates.

The calculations for each are as follows:

[illegible] restaurants, bars and other public places, but not at work or while traveling. Dose = (concentration; home × duration; awake × respiration rate; awake × retention) + (concentration; home × duration; asleep × respiration rate; asleep × retention) + (concentration; restaurant × duration x respiration rate x retention) + (concentration; bar × duration × respiration rate × retention) + (concentration; offices, × duration; other, public × respiration rate × retention).

Male Dose = (27.2 × 6.4 × 1.05 × 0.11) + (27.2 × 7.5 × 0.4 × 0.11) + (41.8 × 0.5 × 1.05 × 0.11) + (103.7 × 0.8 × 1.05 × 0.11) + (21.8 × 1.6 × 1.05 × 0.11)

Male Dose = 45.11 µg/day, 16.46 mg/y

Female dose = (27.2 × 8.7 × 0.65 × 0.11) + (27.2 × 7.8 x 0.3 × 0.11) + (41.8 × 0.4 × 0.65 × 0.11) + (103.7 × 0.9 × 0.65 × 0.11) + (21.8 × 1.6 × 0.65 × 0.11)

Female Dose = 34.28 µg/day, 12.51 mg/y

2) Male and female—exposed only at work and while traveling.

Male Dose = 17.19 µg/d, 6.27 mg/y

Female dose = 6.94 µg/d, 2.53 mg/y

3) Maximum exposure, male and female—exposed at home and while traveling, works in a bar and is also exposed in other public places.

Male Dose = 108.65 µg/d, 39.66 mg/y

Female Dose = 57.62 µg/d, 21.03 mg/y

Table 12. Total time allocations for male/female.

Location	Males		Females	
	Min/day	Hr/day	Min/day	Hr/day
1. Home, awake	386	6.4	521	8.7
2. Home, Asleep	452	7.5	470	7.8
3. Work	296	4.9	167	2.8
4. Travel	81	1.4	67	1.2
5. Restaurant	31	0.5	26	0.4
6. Bar	48	0.8	54	0.9
7. Other, public	94	1.6	95	1.6
8. Outdoor	52	0.9	40	0.7
TOTAL	1,440	24.0	1,440	24.1*

* Totals do not add up to 24 hours due to rounding.

Table 13. Total time allocations, employed, and unemployed persons.

Location	Employed		Unemployed	
	Min/day	Hr/day	Min/day	Hr/day
1. Home, Awake	427	7.1	733	12.2
2. Home, Asleep	511	8.5	499	8.3
3. Work	276	4.6	5	0.1
4. Travel, Public	81	1.4	37	0.7
5. Restaurant	17	0.3	20	0.3
6. Bar	33	0.6	36	0.6
7. Other, Public	61	1.0	68	1.1
8. Outdoor	34	0.6	42	0.7
TOTAL	1,440	24.1*	1,440	24.0

* Totals do not add up to 24 hours due to rounding.

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4) Employed vs. unemployed males—exposed in all facets of lifestyle, employed person works in office environment.
Employed Male Dose = 60.06 µg/d, 21.92 mg/y
Unemployed Male Dose = 62.34 µg/d, 22.76 mg/y.

There are several chemical and exposure pattern differences between direct smoking and ETS exposure. However, expressing ETS exposure in cigarette equivalents is one way to develop a sense of the magnitude of exposure.

Arundel et al. (1988) has calculated a retained dose of particles of 10.56 mg/cigarette and 8.48/mg cigarette for male and female direct smokers, respectively. Using these figures, the dose in cigarette equivalents of particles for each of the four exposure scenarios becomes:

1) Exposed at home, in restaurants and in bars:
Male—1.56 cigarette equivalents per year
Female—1.48 cigarette equivalents per year.

2) Exposed at work and travel only:
Male—0.59 cigarette equivalents per year
Female — 0.30 cigarette equivalents per year.

3) Maximum, works in a bar, exposed in all facets of life:
Male—3.76 cigarette equivalents per year
Female—2.48 cigarette equivalents per year.

4) Employed vs. unemployed males:
Employed—2.08 cigarette equivalents per year
Unemployed—2.15 cigarette equivalents per year.

Clearly, such calculations of cigarette equivalents have little or no relevance to any assessment of the potential risk from exposure to ETS. The mainstream smoke particles inhaled during the act of puffing on a cigarette will be quite different from ETS particles in terms of their precise chemical composition, their size distribution and the route in which they are taken into the body. However, the calculation of cigarette equivalents does at least allow a subjective impression of the relative doses involved in active smoking compared to everyday exposure to ETS.

DISCUSSION

Indoor air and ETS review

Respirable particulate matter: Table 9 shows the mean RSPs in smoking and nonsmoking areas in real life conditions. The mean differences between nonsmoking and smoking conditions are 27.2 $\mu g/m^3$ for homes, 21.8 for offices and public facilities, 41.8 for restaurants, in excess of 48.3 for bars and taverns, and 30 for trains.

Carbon monoxide: Table 10 shows carbon monoxide concentrations (ppm) in smoking and nonsmoking areas in real life conditions. In offices, where the data allowed for a smoking/nonsmoking comparison, the mean difference was 0.28 µL/L (0.32 mg/m^3). Because of the magnitude of this difference compared to the mean levels measured and ranges reported, the significance of this difference must be questioned. There are essentially no data since 1982 on nonsmoking conditions in restaurants or bars. The slightly higher levels in these areas indicate that smoking may account for at least part of the CO.

There is little information on CO in homes. Yuill and Comeau (1989) report on home CO, but they do not indicate whether smoking was present.

The information on CO levels in transportation vehicles indicates little difference between smoking and nonsmoking areas on trains. Buses have higher levels (6.0 µL/L; 6.9 mg/m^3) of CO; but from the information presented it is impossible to determine if the concentration is affected by tobacco smoke or by vehicle exhausts. The higher level of CO (11.6 µL/L; 13.3 mg/m^3) in autos where no smoking took place indicates that the impact is from vehicle exhausts (Flachsbart et al. 1987).

Nicotine: Table 11 shows nicotine concentrations in smoking and nonsmoking areas. Nicotine, as expected, is considerably lower in concentration in nonsmoking compared to smoking areas. The means of 6.2, 5.7 and 3.7 $\mu g/m^3$ for offices and public buildings, restaurants and homes, respectively, where smoking occurred, are extremely low exposures compared to the levels of many other volatile and semivolatile substances found in indoor air. Smoking sections of trains are slightly higher and, as expected, bars and taverns exhibited the highest mean levels (19.1 $\mu g/m^3$).

Nitrogen dioxide: Most studies which measure nitrogen dioxide (NO_2) in the indoor environment evaluate the effect various appliances, such as gas stoves or kerosene heaters, have on NO_2 concentrations. Only three studies attempted to evaluate the impact of ETS on NO_2 levels in homes (Dumont 1986; Good et al. 1982; Hosein et al. 1985). Houses where smoking occurred had approximately 3.0 $\mu g/m^3$ higher nitrogen dioxide levels than houses with no smoking. There are no studies which evaluate the effect of ETS on NO_2 levels in offices, restaurants, bars, or transport vehicles.

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Formaldehyde: There is a substantial amount of information regarding formaldehyde levels indoors. However, little of it evaluates the potential effect of [illegible] levels. Of the literature reviewed, one study of 41 homes (Stock 1987) and one study of two office buildings (Hedge et al. 1990) compared formaldehyde levels to smoking status. The residential study found no increase in formaldehyde levels with increased levels of smoking. The office study found approximately a 10 nL/L (12.3 $\mu g/m^3$) increase in formaldehyde levels in a designated smoking area over a nonsmoking area of one building. However, there was no difference between the designated smoking area in one building and another nonsmoking building. Because of the limited number of samples and the number of confounding sources for formaldehyde these results must be interpreted with caution.

Benzene: Five studies contained benzene data in smoking and nonsmoking areas (see Table 6). In two of these studies, nonsmoking areas reportedly had higher concentrations of benzene. In three studies, nonsmoking areas had lower concentrations than smoking areas. The differences are minimal, especially when outdoor concentrations also are considered.

The assumption was made that in studies where smoking/nonsmoking was not reported by the author, that there was some smoking occurring. Where smoking is assumed to take place, the highest mean level recorded was 15.7 $\mu g/m^3$. However, in nonsmoking areas the highest mean was 60.7. In summary, there are few data to support a conclusion that smoking has a significant impact on benzene concentration in offices.

The data on benzene in homes suggest that smoking homes have a higher concentration than nonsmoking homes by approximately 3.5 $\mu g/m^3$. It is difficult to separate home-only data from personal exposure monitor data except for two studies where indoor air benzene ranges from 4.8-14.8 $\mu g/m^3$. The one overnight study in homes by Wallace et al. (1987) shows an increase of approximately 3.1 $\mu g/m^3$ in smoking homes vs. nonsmoking homes.

There are few data on benzene on public transportation. A paper by Proctor (1989) on 20 trains shows a slightly higher mean concentration of benzene in smoking versus nonsmoking areas. The mean differences are small.

Polyaromatic hydrocarbons (PAH's) and nitrosamines: PAH's are commonly found in indoor air. Except for naphthalene, quinoline, and isoquinoline, the levels measured are in the low ng/m^3 range (Table 8). Few studies have compared PAH levels in smoking and nonsmoking environments. The two [illegible] review which [illegible] areas indicate that between 50% and 80% of the concentration of various PAHs may come from [illegible] smoke. Because of the paucity of data this must be interpreted with caution. The presence of these substances has also been documented in wood smoke, automotive exhaust, foods, alcoholic beverages, and cosmetics (NTP 1989).

Two studies have reported the presence of N-nitrosodiethylamine (NDEA) and N-nitrosodimethylamine (NDMA) in smoke-filled rooms (Table 7). These are not tobacco-specific nitrosamines. The lack of reported background levels and the unusually high level of smoking prevents the evaluation of ETS contribution to these substances. Other nitrosamines reported to be found in tobacco smoke have either not been monitored or not been reported in ambient air where ETS is present.

The U.S. Surgeon General (1986) and NRC (1986) reports include summary tables of known or suspect human carcinogens present in concentrated sidestream and mainstream tobacco smoke. Concentrated sidestream and mainstream tobacco smoke are not representative of ambient air ETS because the concentrated smoke is subject to dilution in ambient air, removal by sinks or filtration, and possible transformation (Reasor 1987).

Based on current literature, it appears that ETS has an effect on the levels of nicotine and respirable particles in an indoor environment. There also is a slight increase in NOx levels in the presence of ETS. ETS appears to have less effect on the levels of carbon monoxide, formaldehyde, or benzene.

Odor and irritation: Studies by Cain et al. (1987), Weber (1984), and Weber and Grandjean (1987) indicate that levels of ETS which produce carbon monoxide concentrations below 1.5-2.0 $\mu L/L$ (1.7-2.3 mg/m^3) also will be acceptable to 80% or more of the occupants in terms of irritation, odor, and overall quality. Where a moderate amount of smoking occurs, this level is unlikely to be approached. This conclusion is reflected in ASHRAE Standard 62-1989 (ASHRAE 1989), which does not separate smoking and no-smoking areas in terms of recommended ventilation rates.

It is possible that the 1.5-2.0 $\mu L/L$ (1.7-2.3 mg/m^3) level of carbon monoxide may be exceeded in some cases. This would occur either in heavy smoking situations, such as those found in bars or smoking lounges, or where inadequate ventilation occurs.

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Dosimetric calculations

One can calculate the doses of RSP retained from [illegible] a female exposed only at work to approximately 49 mg, for a male exposed in all facets of his life. Occupational exposure is only a minor portion of total exposure in most cases. Exposures in one's private life may produce the largest retained dose of ETS particulates.

For exposures received while in transit, it was assumed that all transit time was spent in the smoking section of trains. Actual time allocation data (Jenkins et al. 1990) indicate that only 5% of travel time is spent on public transport. It is believed that when traveling by auto, nonsmokers will generally choose to travel with other nonsmokers. There are no data comparing particulate levels in autos where smoking occurs to levels were there is no smoking. However, carbon monoxide levels of 8.8-22.3 μL/L (10.1-25.6 mg/m^3) found by Flachsbart et al. (1987) suggest that exposures in automobiles come primarily from vehicle exhaust and not ETS. Thus, the choice of trains as a surrogate for ETS exposure while in transit is conservative.

The estimated mean RSP dose of exposure to the population of nonsmoking adults is based on the difference between smoking and nonsmoking environments. There is a possibility that a person could be exposed to the high end of the range of RSPs as reported in the literature. The likelihood is that the bulk of the RSPs in those situations would be from sources other than tobacco smoke.

Persons also may be exposed to the upper limits of ETS—derived RSP ranges. Generally, these are for short time intervals. The mean difference values for the various categories of exposure should reflect the overall minimum and maximum exposure such that the total dose for the year would be included.

Attempts to calculate increased risk or excess mortality from lung cancer (Repace 1985; NRC 1986) and heart disease (Wells 1988; Glantz and Parmley 1991) reportedly resulting from ETS exposure are not uncommon. These calculations, however, rely almost exclusively on epidemiologic studies that have no adequate measure of exposure or dose. Such studies are known to be subject to problems of bias (Lee 1987) and confounding factors (Koo et al. 1988) which have not been taken adequately into account.

One of the paradigms of toxicology is that the magnitude of the dose determines the response. Comparing the dose one may receive from ETS to the magnitude of claimed health effects provides one measure of the accuracy of those claims.

Other studies that have calculated ETS dosage [illegible] discrepancies between the levels of risk calculated in the epidemiology studies and the [illegible] reported by dosimetric calculations. Wells (1988), Repace and Lowrey (1991) have [illegible] to address this discrepancy. Wells argues that the majority of the "tar" fraction of ETS may be in the vapor phase. He claims that this vapor phase would be retained 100%, producing the majority of the dose one would receive. Thus, he suggests that particles are not an accurate measure of ETS dose. However, the compounds he lists as candidates for vapor phase tar components are not convincing in terms of their potential human health effects. They also are substances that have only been measured in concentrated sidestream and mainstream smoke, not ambient ETS. Until levels of these compounds are actually shown to increase in the presence of ETS, his argument must be considered speculative.

Repace and Lowrey (1991) calculate a daily inhaled dose of ETS particles between 1.4 and 14 mg/d. Calculations based on literature values of ETS concentrations from this paper indicate an inhaled dose of between 0.1 and 0.06 mg/d. When one considers that only 11% of these particulates are retained, the actual dose becomes 0.01 to 0.006 mg/d or 1/140 to 1/233 of the dose claimed by Repace and Lowrey.

Until the problems of confounding and bias in the epidemiology studies are resolved, dosimetric considerations can be the only independent confirmation of the accuracy of their claims. At this point, it can only be concluded that the estimated dose of ETS one can be expected to receive does not support the health risk claims being made by USEPA (1990) and others.

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